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TITLE:	PROPERTIES OF STEEL AT ELEVATED TEMPERATURES – CREEP

CONTENTS:

1. Introduction
2. Stages of deformation
3. Creep test
4. Factors contribute to the outcome of creep test

1.0 INTRODUCTION

Creep is the slow plastic deformation of metals under a constant stress that occurs in a specimen to which a steady tensile load is applied over a period of weeks or months. In creep testing, a heating coil fitted with a pyrometer surrounds the specimen. The specimen is heated to a given temperature, the load is applied, readings are taken of the extension that occurs over a period of weeks and a graph on these results is made. The test is repeated for various loads and at various temperatures to establish the creep behaviour of that material. The phenomena of creep are important in those areas where stresses are applied for long periods of time at either ordinary or elevated temperatures. For example –

1. The soft metals used at about room temperature, such as lead pipes and white metal bearings.
2. Gas turbines working at high temperatures.

Creep is a performance based behaviour and not an intrinsic property of a material. Generally, this temperature dependant deformation is defined at absolute temperatures greater than one half of the absolute melting temperature. This relative temperature ($T_{abs}/T_{mp\text{-}abs}$) is known as **homologous temperature**. Generally for creep tests, samples are loaded in the temperature range 0.5 – 0.7 of the melting point T_m (melting temperature in °K).

For example: steel melts at ~1500°C= (1550 + 273) = 1773 K. If for a steel plant, the application is at 650°C (equal to 923 K). The homologous temperature is 923/1773=0.52, so this is consistent with the definition of creep.

2.0 STAGES OF DEFORMATION

The variation of the extension with time of a metal under different stresses is shown in Fig. 1. Three conditions can be recognized:

I. **The primary stage**, when relatively rapid extension takes place but at a decreasing rate. This is of interest to a designer since it forms part of the total extension reached in a given time, and may affect clearances.

II. **The secondary** period during which creep occurs at a more or less constant rate. Sometimes referred to as the minimum creep rate. This is the important part of the curve for most applications.

III. **The tertiary creep** stage when the rate of extension accelerates and finally leads to rupture. The use of alloys in this stage should be avoided; but the change from the secondary to the tertiary stage is not always easy to determine from creep curves for some materials.

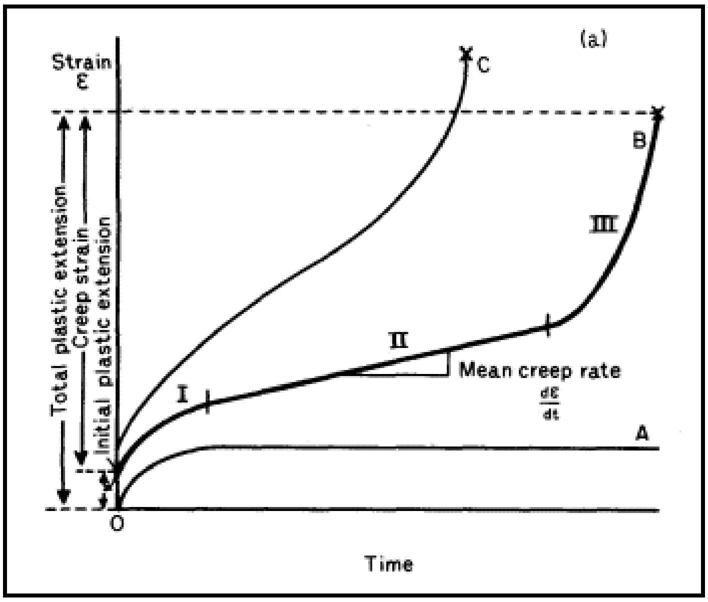

Figure -1: Family of creep curves at stresses increasing from A to C

The limited nature of the information available from the creep curve is clearer when a family of curves is considered covering a range of operating stresses.

As the applied stress decreases the primary stage decreases and the secondary stage is extended and the extension during the tertiary stage tends to decrease.

Modifying the temperature of the test has a somewhat similar effect on the shape of the curves.

Design data are usually given as series of curves for constant creep strain (0.01-0.03%, etc.), relating stress and time at a given temperature.

Since the permissible amounts of creep depend largely on the article and service conditions, in designing plants that work well above atmospheric temperatures, the designer must consider carefully what would be the possible maximum temperature.

3.0 CREEP TEST

Conceptually a creep test is rather simple. Apply a force to a test specimen and measure its dimensional change over time with exposure to a relatively high temperature (typical creep test set up, Figure-2). If a creep test is carried to its conclusion, that is, fracture of the test specimen, often without precise measurement of its dimensional change, then this is called a **stress rupture test**. A comparison of creep and stress rupture tests is shown schematically in Figure-3.

Although conceptually quite simple, creep test in practice are more complicated.

- Temperature control is critical (fluctuation must be kept to <0.1-0.5°C)
- Resolution and stability of the extensometer is an important concern (for low creeping material, displacement resolution must be in the order of 0.5 μm.
- Uniformity of the applied stress is critical. As the specimen elongates the cross sectional area decreases and the load needs to be decreased to maintain a constant stress.

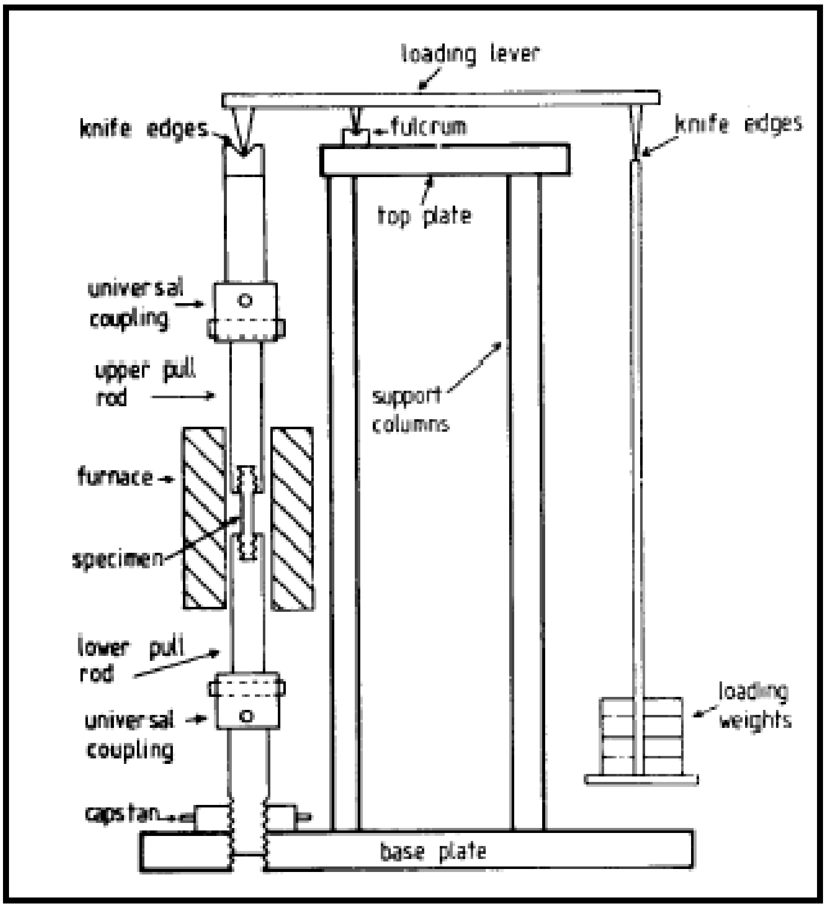

Figure-2: Typical creep test set up

The failure mechanism in creep test is controlled by atomic mobility and related to diffusion. For example, dislocation climb, concentration of vacancies, new slip systems, grain boundary sliding, etc are all diffusion controlled process and will affect the behaviour of the materials at high temperatures. In addition, corrosion or oxidation mechanisms also will have an effect on the life time of materials at high temperatures.

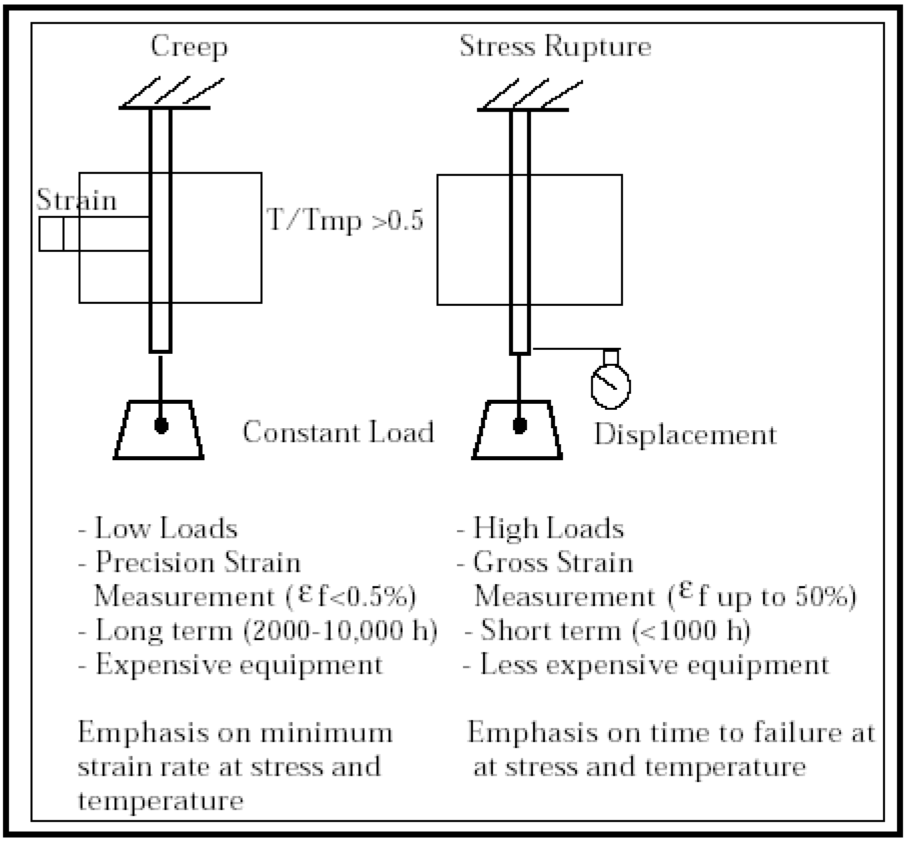

Figure-3: Comparison of creep & stress rupture test

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Depending upon the requirements, short or long time creep tests can be done. For long-time applications it is necessary to carry out lengthy tests to get the design data. Generally for alloy development and production control, short time tests are used. It is dangerous to extrapolate from short time tests to long time creep test data which may not produce all the structural changes, e.g. spherodization of carbide, micro-void coalescence, etc.

3.1 Long time creep tests

A uniaxial tensile stress is applied by the means of a lever system to a specimen (similar to that used in tensile testing) situated in a tubular furnace and the temperature is very accurately controlled. A very sensitive mirror extensometer (of Martens type) is used to measure creep rate of 1×10^{-8} strain/h. From a series of tests at a single temperature, a limiting creep stress is estimated for a certain arbitrary small rate of creep, and a factor of safety is used in design.

3.2 Short time tests

The rupture test is used to determine time-to-rupture under specified conditions of temperature and stress with only approximate measurement of strain by dial gauge during the course of the experiments because total strain may be around 50%. It is a useful test for sorting out new alloys and has direct application to design where creep deformation can be tolerated but fracture must be prevented.

4.0 FACTORS CONTRIBUTE TO THE OUTCOME OF CREEP TEST

The goal in engineering design for creep is to predict the behaviour over the long term. Though the creep mechanisms can be visualized with various strain-time plots, the mechanism of failure must not change with time, temperature or stress.

The factors contribute to the creep failure shall be correlated on the basis of-

- Chemical composition of the material
- Restrictions on impurity elements, if any
- Temperature of testing
- Applied load/ stress
- Strain rate
- The physical state of the material (mechanical work /heat treatment condition)
- Microstructure & grain size, etc.

For an actual fabricated structure, the analysis of creep behaviour becomes furthermore complicated. Apart from the evaluation of creep criterion of base metal & weld metal, the metallurgical changes that take place in the parent metal heat affected zone (HAZ) during welding drastically affect the test behaviour. The extent of micro-structural change, width & coarsening of grains in the HAZ and related precipitation phenomena affect the weldment for the elevated temperature application.

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